UCLA

Title

Review of Integrated Structured Light Architectures

Author

Wu, Jason

Publication Date

2022-12-08

Review of Integrated Structured Light Architectures

Jason Wu[1*]

[1]*Currently with UCLA Electrical and Computer Engineering*

**jaysunwu@ucla.edu*

Abstract: Using phased-array based laser architecture enables the ability to control numerous field properties, allowing for the phase locking of 8 fiber-based beamlines with high finesse.

INTRODUCTION

The ability to manipulate light through structured photonics allows for numerous applications, from cutting-edge accelerators and X-ray free electron lasers [2], to quantum information processing [3]. To fully utilize the potential of structured photonics, it is paramount to gain control over the field parameters of phase, amplitude, polarization, and timing [1].

Classically, structured light is produced through the use of *spatial light modulators* (SLMs), which are capable of controlling the intensity and phase of the output. Current LCD based SLMs utilize voltage induced optical anisotropy to modulate such parameters [4]. However, these methods are bulky and limited to switching speeds of 10 kHz, rendering them a poor choice in high frequency applications. Current state of the art high-speed SLMs utilize nanoscale organic electro-optic molecules to achieve broadband nonlinearity improvement of 10-100 times [5]. However, even state of the art SLMs are power limited, unable to operate in conditions involving mW to W power levels [1].

[1] proposes a tiled phased-array based approach capable of adjusting all parameters of the 3D wavevector, implemented with an FGPA to ensure real-time programmability. It leverages CEP stabilization via an ultralow phase-noise feed-forward technique coupled with a photodiode for measurement, and a phase modulator on each beamline enables precise adjustments.

METHODS

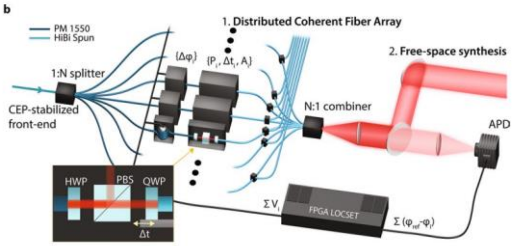

Fig. 1. Experimental Setup (Ref. [4], Fig. 2).

Fig. 1 depicts the high level setup of the system, which begins with a 1:N, CEP stabilized splitter to generate N independent waves. They pass-through N distinct modulators that adjust the parameters of the wavefront, and the combined waveform shines on an avalanche photodetector. The photodetector provides input into the FPGA regarding the synchronization state of the waves, allowing the FPGA to compute the necessary changes to the modulators to ensure perfect synchronization. To capture the polarization vector maps for beam analysis, we obtain a projection image with several waveplates and an InGaAs camera.

The laser oscillator sends out pulses at a repetition frequency of $f_{REP} = 204\ MHz$. The raw signal from the photodiode is filtered to isolate f_{CEO}, and mixed with a local oscillator frequency of f_{LO} to obtain the input $f_{AOFS} = f_{CEO} + f_{LO} = 80MHz$. The f_{AOFS} signal is passed to the FPGA which utilizes mixing and filtering, ultimately converting the frequency signal to a voltage used in a proportional integral controller to modulate the parameters.

RESULTS AND INTERPRETATION

The polarization vector maps were obtained by passing the light through a half wave plate, polarized beam splitter, and quarter wave plate. A half wave plate of thickness $l_{\frac{\lambda}{2}} = \frac{\lambda}{2|n_y - n_x|}$ [6] adds a polarization shift of 180 degrees to the incident beam while rotating the angle by 2θ. This provides the ability to rotate the polarization angle of any linearly polarized wave. A quarter wave plate of thickness $l_{\frac{\lambda}{4}} = \frac{\lambda}{4|n_y - n_x|}$ [6] shifts the polarization by $\pi/2$, which converts a linearly polarized wave to a circularly polarized one. The purpose of the polarized beam splitter is to split light into parallel and perpendicularly polarized light. Polarized beam splitters can leverage the Brewster angle, where there is 100% transmittance for TM polarized waves, causing all the reflected light to be S-polarized. By chaining all the components together, the half-wave plate modulates the ratio of S and P-polarized light, which creates any ratio of transmittance to reflectance in the beam splitter, controlling the output amplitude. The quarter wave plate transforms the polarization from linear to circular, which allows it to propagate through the *circularly birefringent fiber* without distortion.

This work also utilized an AOFS frequency mixer, which leverages the pressure differential created by sound waves at frequency Ω to create diffraction in the input beam and alter the frequency ω. Since the AOFS first diffraction order produces $\omega \pm \Omega$, this was utilized to not only mix in local oscillator signals, but also to perform frequency subtraction.

The experiments obtained the Stokes projections and demonstrated the wide variety of possible topographies that can be generated with relatively few channels. Furthermore, they also conducted a review of how topological purity was influenced by the channel count. The mean squared error between 7 beams and the ideal was 0.0016, while increasing the channel count to 37 dropped the error to only 0.0006.

CONCLUSIONS

This work demonstrated the ability to control all parameters of a wave in real-time to create highly tailored beams. Through independent modulators on each beam controlled by an FPGA, the system is capable of real-time adjustments with a high amount of reconfigurability. They demonstrated its ability to synthesize high finesse beams with a various number of channels, obtaining minimal mean squared errors. Unfortunately, the design of the system involves many components, and likely is not easily reproducible for an individual wishing to implement this design. Future work can be undertaken on simplifying the system and investigating the trade-offs between system complexity and quality.

REFERENCES

1. *Lemons, Randy, et al. "Integrated structured light architectures." Scientific reports 11.1 (2021): 1-8.*
2. *S. Carbajo, "Structured Photonics in Light-Matter Interactions, Accelerators, and X-ray Lasers," 2021 IEEE Photonics Conference (IPC), 2021, pp. 1-2.*
3. *Biolatti, E et al. "Quantum information processing with semiconductor macroatoms." Physical review letters vol. 85,26 Pt 1 (2000): 5647-50.*
4. "Spatial Light Modulators." *HOLOEYE Photonics AG*, https://holoeye.com/spatial-light-modulators/.
5. Benea-Chelmus, IC., Meretska, M.L., Elder, D.L. *et al.* Electro-optic spatial light modulator from an engineered organic layer. *Nat Commun* **12**, 5928 (2021)
6. Liu, Jia-Ming. *Principles of Photonics*. Cambridge University Press, 2017.